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ABSTRACT

This paper discusses educational technology and the structural changes that society must make to accommodate it. The paper begins by examining technology trends, including the exponential rate of change in the information industry, the growing ubiquitousness of computers, inequities in U.S. schools, and technology characteristics (e.g., the open source movement and globalization). Dreams of transformed education are then considered. These consist of: new tools, including literacy tools, design tools, tools for concepts, tool scaffolding, and the new textbook; and online courses, including online courses for students, online courses for teachers, and metacourses (i.e., online courses about online courses). It is concluded that schools need to undertake major changes to fully exploit technology. Includes an author biography. (MES)

Ice Machines, Steamboats, and Education: Structural Change and Educational Technologies

By: Robert Tinker

ICE MACHINES, STEAMBOATS, AND EDUCATION:

STRUCTURAL CHANGE AND EDUCATIONAL TECHNOLOGIES

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ICE MACHINES AND STEAMBOATS

Every revolutionary technology starts with a whimper. Its full revolutionary bang is realized only later after fundamental structural changes are made to accommodate the new technology.

Paul Horwitz likes to remind us that the first ice making machines were introduced when everyone used iceboxes to store food. Ice companies delivered blocks of ice for these iceboxes once or twice a week. Of course, the first ice machines were used by the ice companies to make ice for home iceboxes. It took decades until the ice companies vanished and everyone had personal ice machines, called refrigerators.

Steam engines were first put on sailboats to solve a persistent problem: time wasted in the doldrums. When there was no wind, the steam engine was fired up and used only until there was enough wind for sailing. Steam was initially viewed as a solution to a problem for sailboats, not as a replacement for them. But, of course, in the end sail power vanished and steam permitted faster, larger, safer, all-metal ships that could move goods faster and much more economically.

There are countless examples like these in the history of technology, where a new technology is first used to address a narrow problem within the existing order and only later overthrew the old order. The delay is inevitable because structural changes are needed for the new technology. In the case of ice machines, universal access to electricity and lower costs through mass production were needed before everyone could buy a refrigerator. In the case of steamboats, deeper harbors, new construction techniques, and railroads to supply coal and remove cargoes were needed before large, steel steamers made sense.

There is dawning realization that the current economic boom has technology to thank because of the structural changes it has caused in business. Productivity is up because technology means that fewer managers are needed, businesses are far less hierarchical, and financial markets have been democratized.

In spite of the decades that computers have been around and their current high use in schools, we have yet to see the revolution they could cause in learning. Educators are still delivering block ice made by ice machines, still using steam only in the doldrums. This is because business competition rewards improvements while education is organized to conserve and pass on the best of the old. In addition, education is highly labor-intensive, and the cost of labor has been bid up by the buoyant economy. We are, nevertheless, overdue for a surge in education performance driven by the technology, as soon as we are willing to make the necessary structural changes. This will profoundly improve education.

TECHNOLOGY TRENDS

Before jumping into the specifics of the educational change that technology will cause, it is important to understand where we are in the information revolution and where it is going. We must look at not only the technology itself, but also the structural change society must make to accommodate it.

Moore's Law

We are only part way through fundamental improvements in the technologies that enable computers and networks. The technologies we see today will look feeble and clumsy tomorrow because the technological revolution is far from complete.

One indicator of this ongoing change is "Moore's Law", an observation made by Gordon Moore in 1965, several years before helping start Intel. Moore observed then that the number of transistors on a microchip was doubling every 18 months. As Figure 1 suggests, this incredible rate of advance has remained true for 30 years, and could for another 30.

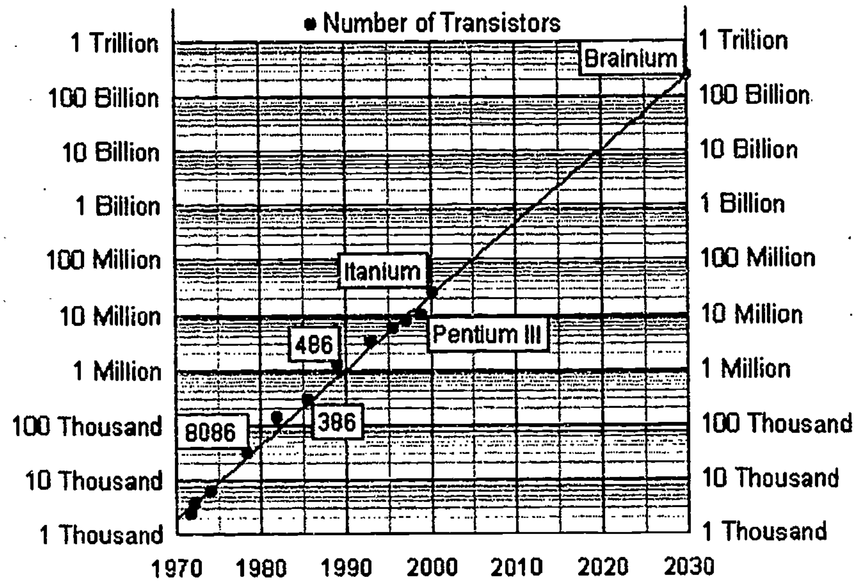

Figure 1. Moore's Law. Note that the vertical scale on this and the next graph is logarithmic. Source: http://www.chartoftheday.com/20000719b.htm

This kind of exponential change applies to the entire information industry, not just computer chips. In 1995, I collected historical data on hard drive costs from advertisements in old magazines. The result is graphed in Figure 2 and extrapolated to 2002. These data show that the cost of 1GB of storage has dropped by a factor of two every year. I recently checked the data for 2000 and found that my pre-1995 prediction was correct within the width of the line. Similar exponential increases in performance will be seen in all components: displays, keyboards, and media.

This unprecedented level of change is certain to have huge consequences. For comparison, Figure 2 shows the factor-of-three decrease in costs achieved by Henry Ford over six years. This change democratized the automobile, led to malls and suburbs, and revolutionized all kinds of manufacturing through mass production. Ford's innovation is miniscule and glacial in comparison to the decades of annual factor-of-two change in computer and networking performance we are witnessing.

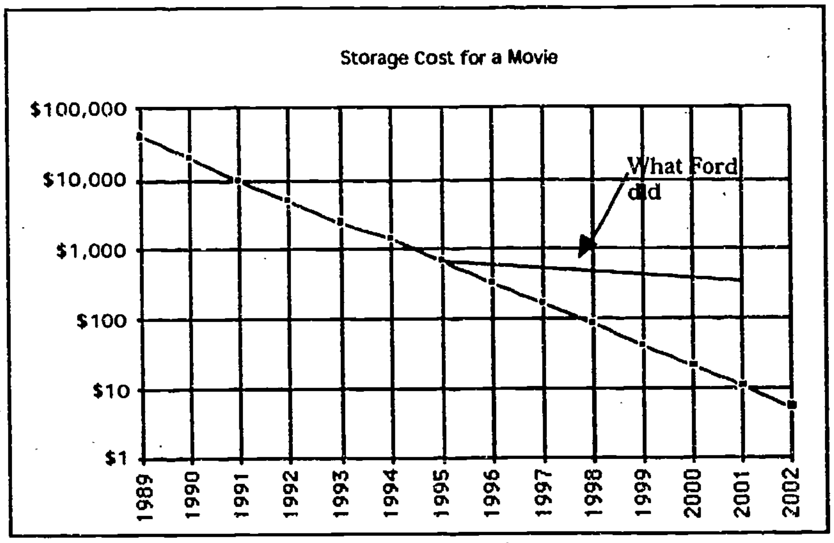

Figure 2. ***Costs of storing a compressed movie on a hard drive.*** *Based on data for 1989-1995. The other points are extrapolated but are accurate for 2000.*

Experts expect these changes to continue 10-20 more years, but no one really knows. The result might be a trillion-fold increase in performance since 1965 and a million-fold increase from today. It is impossible to predict what new applications that these improvements in the underlying technology will enable, but it is certain that the structural changes necessary to exploit them fully in education will take additional decades.

We are helping write the script of the opening scenes of the most dramatic play educators have ever witnessed. Our grandchildren will write the final scene and their children will enjoy its impact.

Ubiquity and Convergence

A direct consequence of the ongoing revolution described above, in only a few years computers will be very inexpensive and ubiquitous. Each person will own several and have easy access to more--all able to communicate over the Internet. Toys, TVs, phones, pagers, handhelds, and general-purpose computers will have access to the net. Wireless access will become common and switching between wired and wireless connections will be effortless.

There is great concern that this will only lead to another wedge between rich and poor, the "digital divide". Figure 3 illustrates the situation. In terms of classroom access to the Internet. The poorer schools appear to be about two years behind the richer ones. This difference is inexcusable, but using my projections[1], the rich-poor numerical difference almost vanishes as both approach 100% access by 2002.

Any indicator of technology access in the U.S. will show a similar behavior over the next decade, showing a gap that dwindles into insignificance as prices drop. This is because information technologies are relatively low-cost and dropping. Unlike jets, reactors, and rockets, computer and network technologies are "democratic technologies." Like TVs, VCRs, calculators, and radios, information technologies are soon to be ubiquitous.

[1] The projected data represent a fit to an arctangent function. Because there are only four points of data, there is considerable uncertainty in the projection.

The vanishing of the digital divide defined as access to technology in the U.S. will not, of course, rectify the deplorable inequities in U.S. schools. Because of inadequate funding and more difficult working conditions, too many poor schools will not use the technology well, will be unable to maintain it, and will provide fewer opportunities for their teachers to exploit it. The result will be continued poorer education in many poorer schools. The cost of access to technology will not contribute significantly to this persistent, essentially political, problem. If anything, the technology, by providing free access to increasingly valuable resources, will have a leveling effect that will tend to reduce the gap.

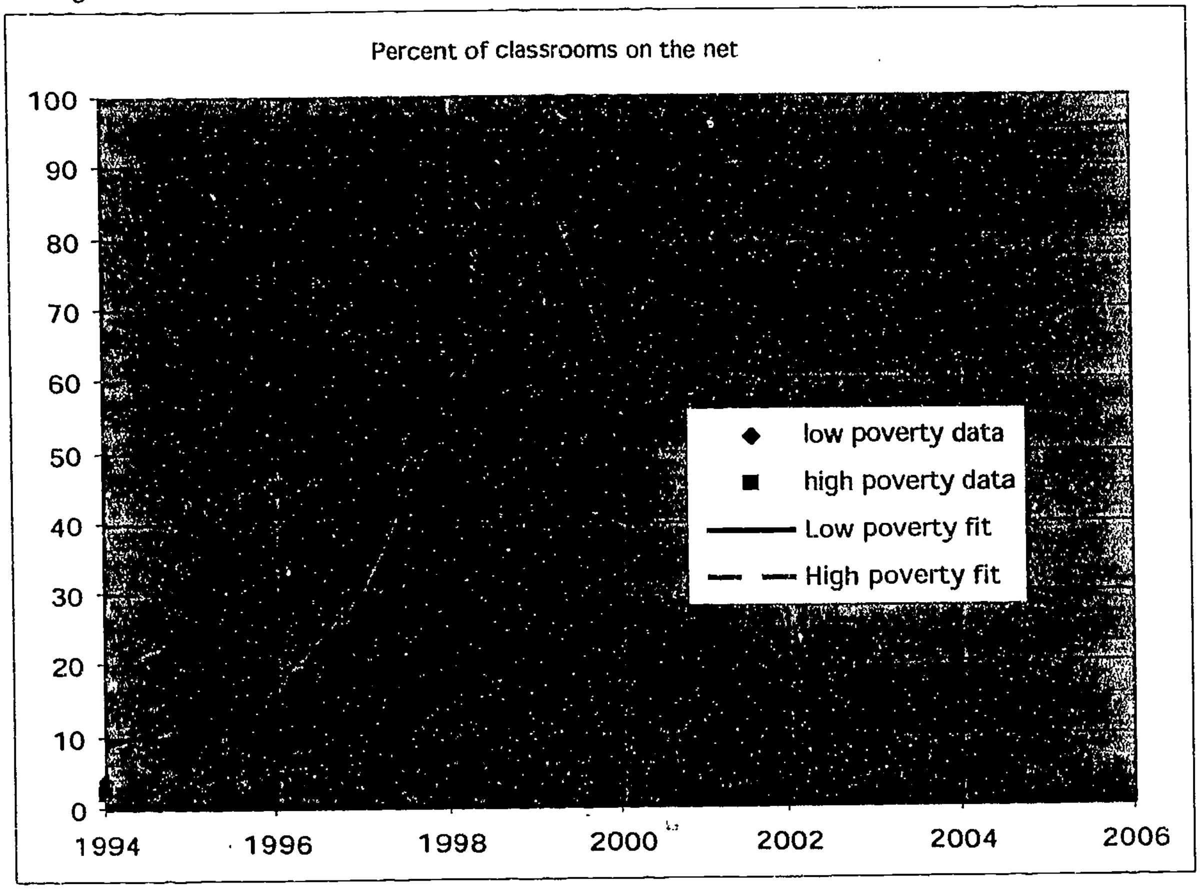

Figure 3. The Digital Divide: Percent of U.S. Classrooms with Internet Access by Poverty Level. *The top graph is for schools with fewer than 11% of students participating in free or reduced lunch programs. The lower line shows schools with more than 70% participating. The gap is one measure of the difference between schools serving rich and poor communities. Data for 1994-1999 are shown, the curves are extrapolations[2].*

The situation throughout the world will be essentially similar, with the exception of much of central Africa. In most parts of the world, the huge digital divides that exist today will close as access becomes ubiquitous. Many countries already exceed the U.S. access to technology and

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[2] http://nces.ed.gov/quicktables/Detail.asp?SrchKeyWord=Internet+&Key=277&optSearch=Exact&quarter=&topic=All&survey=All&sortby=

even developing countries see the importance of computer and networking technologies and are making them widely available.

Ubiquity will be accompanied by increasing reliance on the network to synchronize data. You want your personal mailing list to be on your cell phone and TV computer. If your student masters multi-digit subtraction in school, her educational games at home should take advantage of this and her parents should be informed. Data collected on a colleague's handheld computer should be available on your portable. All these feats of synchronization will happen automatically and effortlessly through the network. The location of the data will not matter; you may choose to store your data on your main computer's hard drive, a server in Budapest, or for security, your personal smart card.

It is quite likely that each learner will have a net-based educational profile that can change as the individual learns. This is how a student's progress can be monitored, shared among different computers she uses, and reported, as appropriate, to parents and others responsible for her education. Leapfrog, a maker of educational toys, is already planning a line of mass-produced products based on this principle.

An online educational profile is a potential privacy bombshell. Everyone will want tight and secure control over who looks at grades, test scores, progress, weaknesses, essays, and preferences. Technology can solve this, though, through some combination of encryption, a smart card that physically controls the data, and related software.

Technology Characteristics

Before projecting educational uses of technology, it is useful to summarize the unusual characteristics of networking technologies. These characteristics have led to the Internet's impact on commerce and have dictated the structural changes needed to exploit fully the technology in business. We can look at these for hints about the similar structural changes needed in education.

Open Source

No one owns the Internet. The power of the Internet is that almost anyone can contribute to it and there are ways to find anyone's contribution. This could lead to the junk and misinformation drowning the relatively rare pearls. This is unlikely, however, because the decentralization also supports self-appointed annotators and collectors of links that provide vetting and review functions. In fact, this self-publishing feature has unleashed tremendous human creativity. Every corporation, government agency, school, town, association, group, museum, and individual wants to put their best on the net.

One of the most dramatic manifestations of the ethic of sharing that the Internet has spawned "open source". The open source movement is highly decentralized, but rallies around the idea of the GNU Public License (GPL) as an alternative to conventional copyright protection. The GPL states that anyone can use the source code without charge providing the user protect any improvements with the GPL license. Companies can sell the software, providing that they continue to make the source freely available. The result is that the source code stays public and keeps getting refined.

GPL software can be better than software simply placed in the public domain, because the terms of the GNU license stop anyone from grabbing the public code and making it proprietary. The result is code that everyone is motivated to review and improve the code. Code that survives tends to be lean, elegant, stable, and free.

Initially, open source software focused on the Linux operating system software, but this is changing rapidly. The people shaping the effort insist that system software is only the beginning. Because open source development is the best way to create reliable and elegant

software, they are certain that most software will eventually be distributed under the GPL. The open source motto is "Software is meant to be free."

They may be right. Already the open source idea has reached far beyond Linux. In addition to the Netscape browser, there are now open source spreadsheets, word processors, a presentation package (like PowerPoint), and gimp, an image manipulation program that is better than PhotoShop. The open source software idea is beginning to appeal to corporations, because it offers an inexpensive way to incorporate free software into their product and get better product support than they can afford to hire. All Netscape's code is open source, as is much of the next generation Macintosh operating system. IBM is installing GNU/Linux into some computers.

Globalization

The U.S. has led the world in Internet use and implementation, but the rest of the world will overtake us soon. The largest growth in Internet use over the next few years is expected in Latin America and Asia. According to Global Reach, currently, 49% of the 335 million Internet users worldwide are non-English speaking. In 2003, the 670 million non-English users will be more than double the number of English-speaking users. There are already 18 million Chinese users and there might be 125 million in 2003[3].

While these projections are open to question, the general trend is not. The majority of the educated population of the world along with most of its institutions will be strutting their stuff online in a few years. These new users will bring a rich collection of new resources and interests to everyone. The world's books, art, data, pictures, animations, music, simulations, poems, and much more will be available. Collaborators, collectors, mentors, advisors, and consultants for every imaginable topic will be a few clicks away.

Unfortunately, all kinds of undesirable resources will also be increasingly available. There will be the entire world's junk, smut, hatred, violence, stupidity, superstition, and insanity. Every form of vice and bad habit will be represented, too. Even more viruses will be circulated and more attacks on computer systems mounted. In addition, the Internet is rapidly becoming commercialized. Some of the most amazing services are available free, subsidized by advertisers. Computers, email, storage, faxing, news, music, search engines, financial data, and much more are available free because they are paid for by advertisers.

There is no point in avoiding the Internet because of these undesirable aspects. We have to face the problems and learn to minimize them. One of the skills we will need to learn is how to find the good, reliable stuff for ourselves and youngsters in our charge while avoiding the bad.

DREAMS OF TRANSFORMED EDUCATION

Given these trends and directions, what are the implications for precollege education? What kinds of change will be the most important over the next decade? How will these changes affect schools, teachers, and students? How can these change best be managed? It is impossible to answer these questions with any confidence, but there are some areas that are quite promising that I would love to explore.

My work consists largely of writing proposals about ways technology might help education and helping launch the ones that are funded. I have a magnificent staff that converts the dreams we write about in proposals to real projects that help us glimpse into the future. We try to propose work that is important, original, and path breaking. However, our proposals are frequently rejected. In this section, I have dusted off some of my favorite rejected proposals. I like to think that these have been rejected because they are too far ahead of the funders, not bad ideas, or poorly written projects.

[3] Source http://www.glreach.com/globstats/index.php3

New Tools

Software tools have revolutionized business and hold the key to breakthroughs in education as well. Software tools are general-purpose, flexible applications that you can apply to your specific needs. In business, spreadsheets, presentation software, and communication tools have empowered workers to make decisions and marshal resources without the need of levels of hierarchy. Design tools have sped the development of new devices and software, increasing productivity.

In education, tool applications will also lead increases in learning and productivity in all disciplines. Literacy tools are revolutionizing the language arts, design tools have broad application across the arts and engineering, and conceptual tools will completely change all technical and social science learning.

For a tool to be educational, it needs to be part of an instructional design. Software can help there, too, especially if the tool and pedagogy are separated. All these new tools will be too expensive to develop from grants and corporate investments but open source can solve this problem.

Literacy Tools

Technological tools will become increasingly important in teaching literacy and second languages to children, adults, and special students. Over the next few years, there could be important breakthroughs in technology-enhanced literacy learning, because there is a convergence of developments:

Voice recognition. Research is underway on computer recognition of children's voices and speakers with accents. This ability can be used to recognize reading, judge accuracy, and shape pronunciation.

Ubiquitous technology. The coming inexpensive ubiquitous computers will give all learners could access to inexpensive literacy tools.

Networking. Students can use networks to find an audience for their work, a community of interest and collaborators for their investigations.

Game machine quality simulations. The incredible graphics capacity of new 128-bit game computers may create the emotional impact that can capture any learner's imagination.

Embedded assessment. Computer generated material can continuously evaluate student reading and writing, reducing wasted testing time.

Inexpensive handhelds will soon be able to exploit these developments to provide interactive voice generation and recognition. With embedded assessment, the material can advance as fast or slowly as the learner needs. Playful content will be available for young readers while vocationally-relevant material will better suit adults.

While human intervention, motivation, and supervision will be necessary, the ubiquitous technology and software tools will greatly reduce the amount of teacher time required for literacy instruction. The bulk of the reading, listening, and correcting can be shifted to the computer, resulting in huge productivity breakthroughs. This could result in literacy gains worldwide, while decreasing the advantage families have that can find the time to read to their children extensively.

Design Tools

Software tools that support creativity are one of the great gifts of computers. Design tools for Web development, robot programming, and music composition are available and increasingly used in education.

Design as a subject is under-represented in schools today. Design is at the core of engineering, architecture, many technologies, and art. The success of many businesses depends on their

technical and artistic designs. Successful designs depend on planning, testing, knowledge, and artistic sensibilities. A central goal of education should be to foster these skills.

Perhaps the root of the lack of emphasis on design education has been a perception that design consists of two parts that each seem to be problematic. Its creative side has lacked expression outside art class and may seem too intuitive and lacking in theory that would give educators something to teach and evaluate. Design's other face is technical and may be judged as too difficult and abstract for pre-college students.

Again, computers and networking provide tools that can solve both problems. Tools for Web authoring, image manipulation, drawing, and 3D rendering allow students to be creative and share their creations with others. There are meaningful concepts and skills students need to acquire in all areas of design that can be gained through the use of these tools. On the techncial side, design and modeling tools can help students understand the technical ideas underlying design without having to master abstract mathematics or complex programming languages.

Logo and its extensions—Boxer, StarLogo, NetLogo, and Microworlds—represent one important set of tools that make design education feasible at the precollege level. Logo has gotten a bad rap in education because it was ahead of its time. It was embraced by pioneers as THE answer to "computer literacy" and subsequently widely adopted for all the wrong reasons. The resulting backlash has left many educators with a persistent bad taste. This is unfortunate, because the Logo idea and the work of its inventors from MIT's Media Lab have articulated a new approach to education based on design.

Schools need to increase greatly their emphasis on teaching design. This will require fundamental structural changes in education. New goals will have to be articulated, standards articulated and courses developed.

Tools for Concepts

Profound learning happens when models student build to simulate reality meet data students collect. The combination of sophisticated data acquisition from probes and Internet databases with models that can be compared to data, can lead treakthroughs in learning.

An example might be helpful. "Kinetic Molecular Theory" is commonly taught in middle school science. The usual approach is to introduce a series of postulates roughly along the lines of "in an ideal gas, there are no attractive forces between molecules. These molecules act as point particles that bounce off on another like pool balls without loosing energy." It is then asserted that these postulates predict the gas laws, but no justification is provided for this assertion.

This must leave most students quite perplexed. First, the "ideal" gas is clearly incorrect; its molecules are not point particles, and there are forces between them. How can a "theory" built on these patently incorrect assumptions lead to "laws"? Why should students take on faith that the postulates predict the gas laws? What does this tell students about theories, laws, and the conduct of science? The inaccessibility to students of the derivation of the gas laws makes science itself seem inaccessible.

It is now possible to give students a computer model of large numbers of atoms in a container. Students can change the size and forces between atoms and measure the resulting relationships between pressure, temperature, and volume. They can see how these macroscopic properties emerge from atomic properties and interactions. The gas laws are obvious consequences this system, as is phase change, latent heat, and crystal structure. Using probes, the gas laws and latent heats predicted by the model can be quickly verified in real systems.

Instead of the apparent complexity and inaccessibility of KMT as usually treated, this technology-rich approach clarifies the underlying concepts and relates the non-ideal properties of real liquids and solids to an ideal gas. The entire vocabulary of "ideal gases" and "KMT postulates", as well need to assert without proof that there is some relationship between

the two, becomes unnecessary. The result is that students learn at a deeper level without encountering the confusion and apparent contradictions inherent in the usual approach.

We can teach ideas like KMT more deeply because the computational power of modern computers give us a new way to understand abstractions. Until computers, the only way to relate the postulates of KMT with the gas laws was through formal mathematics and the advanced undergraduate level. Students had to wait that long for a fully satisfactory understanding. Even then, the formalism is so difficult, students often fail understand the science. Thus, educators at the precollege level have no choice but to present the material as facts that must be memorized and taken on faith.

The combination of computer-based data collection and modeling can cause a breakthrough in student learning because it provides an alternative and more accessible way of understanding abstract concepts. Instead of using complex formal methods, a higher degree of student understanding can be gained by interacting with a suitable model. Deeper learning accessible to more students can be expected in all the sciences, mathematics, technical fields, quantitative social sciences, and business. Genetics, macro-economics, chemical reactions, evolution, space shots, fire fighting, the stock market, global warming, epidemics, urban planning, and much more can be better understood through DOING it with a model than reading about it or trying to understand it through mathematics. The result will eventually be that many more abstract concepts will be taught at the pre-college level. This is essential to our economy because it is exactly these abstract ideas that fuel our economy.

This breakthrough will have profound effects on special students. For some, this will be liberating, for others, the increased emphasis on conceptual understanding will be make math and science even more baffling. The shift will probably catch many special educators napping who rely heavily on software for drill and practice. Since few special educators are strong in the concepts of science, math, and technology, becoming more concept-focused will put more pressure on classroom teachers to adapt to the needs of special students.

A major structural change will be needed to take advantage of modeling and data analysis tools. Teachers will be needed who have a deeper understanding of their subjects and who know how to teach these concepts with the appropriate use of educational technologies. Educators at all levels will have to adjust to the increased learning that is possible, including the test makers, standards setters, colleges, and schools of education.

Tool Scaffolding

I argue that technology-induced advances in student understanding will be build largely on the increased use of educational tools. Unfortunately, tools have proven hard to use in education. Makers of educational tools have always had a problem: do you produce a simplified version for the learner or one with every conceivable feature for the expert? The stripped-down version is hard to sell because some other tool will have more features and get a better reputation. On the other hand, a full-featured tool is hard for teachers and students to master.

One alternative is to add educational content into the tool. One form of this is "scaffolding", a variety of helping strategies that fade away as the user becomes more expert. Context-sensitive help, that annoying assistant-in-a-window in Microsoft Office, and tutorials are other strategies to address this problem.

The alternative is to separate the tool from the pedagogical software. The tool should have no pedagogical strategy built into it. Instead, it should have "hooks" to a second software package we call Pedagogica. This is an application that is designed for controlling tools to achieve learning objectives. Pedagogica can control how many options the user sees, sense what users do with a tool, and interact directly with the user. By changing the script that Pedagogica executes, it can provide help, scaffolding, or the full-featured tool. This means that the educational strategy is not determined by the tool and can be changed to adapt to the needs of the curriculum and students.

One of the benefits of a tool like Pedagogica is that it can provide embedded assessment. The script that controls what material is presented to students needs to make judgements about what to present. This requires assessment of student learning that can be embedded in the tasks. For instance, consider the script that is used with a model of atoms in a box to teach that pressure and temperature are proportional under some conditions. The script can observe whether a student has considered enough conditions to make this prediction. It can suggest new conditions and then observe what generalizations the student makes. Watching and guiding this kind of problem solving will give the software detailed data on what the student knows and can do. These data are essential for the software to provide useful guidance. It also provides invaluable assessment data. The software can tell what a student has done, how long it took, how many blind alleys were pursued, and how persistent these errors were.

We are building a graphical interface for Pedagogica in which the script closely resembles a concept map. This will allow educators to think in terms of concepts and understandings that are familiar and closely related to the mental models we hope student will develop. Pedagogica is very much a work in progress, but something like this is needed to unleash the educational potential of general-purpose tools. We need to reach broad agreement on the need to separate pedagogy from tool applications and for the technical specifications of the "hooks" tools need to communicate with something like Pedagogica.

Open Source

How are we going to produce the tools that could revolutionize education? It is rare that grants for educational research provide sufficient funding for new tools. Surprisingly, industry also seldom concentrates enough resources for a new tool. It seems that the educational market is too small and slow to respond for businesses to risk the development of new educational tools. Open source provides the best way to develop the needed educational tools.

Open source software exists outside the normal commercial distribution channels, but supports commercialization and a flourishing service industry. Businesses, from startups to IBM and Microsoft, surprisingly have learned to embrace open source. On the other hand, education has essentially ignored it.

Why is there so little open source software for education? The only significant educational open source is a version of Logo by Brian Harvey and a productivity package, Star Office, that could see broad use in education. NSF sponsored research sometimes yields valuable educational software that is free during development, such as various versions of StarLogo, Image (image processing software), and Biologica (genetics simulations). Technically, these are not open source, since their developers retain the right to commercialize the software eventually.

One of the reasons for the paucity of open source educational software is that the open source may need to be nurtured through enlightened self-interest. Once there was a critical mass of open source system software it was in everyone's interest to expand that core. If a hacker needed a Linux driver for an obscure printer, he or she would write it and be bound, under the terms of the GPL, to contribute it to the common good. There was also recognition from gurus for solid, well designed contributions. This suggests that educational open source could provide general-purpose languages, tools and simulations, especially if it was seeded with a critical mass and there were recognition for important contributions.

The critical difference between the current open source system and its possible application to education is the consumers. In the former case, the consumers are techies who can use the software with little or no assistance or ancillary information. In education, the consumers are non-technical teachers and will need curriculum materials and professional development to use open source software. Perhaps this is not as large a distinction as it appears, however. As the interest in open source has expanded, intermediaries have sprung up who consolidate and test open source software, provide documentation, and make it self-installing so that even non-technical users can install it.

Open source educational software is certain to receive increased interest as other countries begin to explore educational applications of technology. For instance, open source educational software is already beginning to make an impact in Mexico. A university-based group had developed a graphical user interface for Linux and some applications that are being distributed free to all schools. Compared to the U.S., education in most other countries is more centralized, more closely connected to higher education, and far less likely to spend money on commercial software. As a result, there will be funding for software that will be distributed freely to schools. Since each country will have similar needs, it makes sense that software development be shared, and open source offers the best alternative.

If funding is provided to seed and coordinate an international educational open source movement, we could unleash the kind of global creativity that has created and expanded open source software for business. The educational open source effort should concentrate on general-purpose tools with standardized hooks for pedagogical controllers like Pedagogica. If educational open source started this way, then enlightened self-interest could accelerate the process. General-purpose tools could find worldwide application. Scripts would adapt the tools to the special needs and goals of specific countries and regions. If tools and scripts were open sourced, then every developer would have a powerful incentive to adhere to open source rules.

There is certain to be thousands of bright, creative programmers throughout the world who would be thrilled to have the chance to contribute to improved education everywhere. The resulting educational tools and pedagogical scripts could be far more sophisticated and extensive than anything we can hope to develop through grants and business investment. A coordinated effort to seed open source development could yield a rich harvest of educational applications that would be far better and broader than current software and completely free.

The New Textbook

This vision of learning that relies on tools guided by scripts using open source software leaves little room for traditional textbooks. Current science texts for high school courses can exceed 1,000 pages and weigh more than a portable computer. They require, with associated materials, years and millions of dollars to develop. The texts must include every topic any significant sub-audience might want, while avoiding potential controversies. This huge investment results in high prices, the use of copyrighted content, and the inability to include public domain materials. This approach to curricula yields heavy, expensive books that are frozen in time. Even if they include software and Web pages, these ancillary materials only begin to scratch the surface of what is possible. They certainly fail to include sophisticated modeling and data collection tools. The textbook-based approach to teaching science is too limiting and too inflexible; it belongs to the prior century.

The realization of the power of technology requires a structural change in curriculum design and dissemination. Let's stop thinking of a textbook and substitute instead online tool-based curriculum resources that are far richer than simply an online textbook. The value of a textbook and its ancillary materials is that it represents a coherent *aggregation* of resources and educational activities. Technology can provide the benefits of aggregation while avoiding the costs, inflexibility of a text and constraints of needing to own all the materials.

This aggregation can be achieved through a flexible online curriculum framework with "slots" for modular digital materials that adhere to high standards. These slots might feature lab activities, software-based investigations, discussions of videos, structured investigations of a model, or research projects. The modules that fill the slots will come from sponsored educational R&D, academic researchers, teachers, or businesses. This modular structure would ensure far faster integration of materials originating in R&D labs that now often languish without a publisher.

It is often incorrectly assumed that relying on digital materials isolates learners and deprives them from opportunities for direct, hands-on learning. It is certainly possible and desirable to

include in the curriculum collaboration and discussions both online and in-class and also give students ample opportunities to hands-on learning using probeware, off-line projects, activities, and field studies.

A complete curriculum would consist of a framework with all slots filled with excellent, highly interactive, research-based materials that take full advantage of data and modeling tools. The result will be richer than a text, because it will provide interaction, computation, and collaboration in the context of learning resources.

A complete set of curriculum materials of this sort for a course might be produced with the same care as current texts, but be based on modules that can be easily modified or substituted for other materials as they become available. States and districts could modify the materials to fit their standards and interests. The modules requiring specialized labs, software, or technology could be modified to fit whatever a school has implemented. Some modules would be free, others would be licensed with a small fee in lieu of the textbook purchase costs, going to the authors.

Implementing these online curriculum resources will require that all students have easy access to computers and networking. As shown in a Figure 3, this will require a few more years to be fully inclusive. This is, however, no reason to fail to start exploring this alternative to texts now. By the time high quality, fully integrated digital curriculum frameworks can be developed, filled, and tested, the technology will be ubiquitous.

Online Courses

Tools, even with excellent pedagogical software, are not going to revolutionize education alone. These critical elements need to be integrated into courses students take. The process of changing courses can be excruciatingly slow. Effective online courses are can accelerate this process by disseminating improved materials and techniques while also creating competition that can stimulate change.

I use the "effective" qualification because too many online courses are not. Most initial efforts were comparable to the first steamships. They represented a straightforward transfer of existing courses onto the net, using one-way audio or video lectures, online texts, and standard tests. To be effective, online courses need to be quite different.

Effective courses are able to engage students at a distance in collaborative, activity-based learning, in small groups guided by trained facilitators. The best approaches use asynchronous, two-way technologies that rely on carefully designed activities, good evaluation strategies, and communities of learners facilitated by online discussions. They also take advantage of the computer for simulations, models, data collection, calculations, mentoring, and creations as appropriate. Well-designed online courses are at least as good as face-to-face courses and are usually more inclusive and better designed. Only a fraction of the online courses fit these characteristics, but time will weed out the many poorer designs.

Online Courses for Students

Online courses for secondary students are exploding. At the advanced level, high school students can enroll at colleges and universities, one-third of which now offer Internet-based courses for credit. Although slower than post-secondary education to exploit the power of online courses, high schools are increasingly offering effective online courses to their students.

Secondary education has lagged colleges and universities in using online courses because few schools have the incentives or resources to offer courses themselves. Post-secondary institutions have strong financial incentives to increase income from tuitions from distant students. High schools are chartered to serve a community and cannot increase their income by stealing students from other districts. In addition, post-secondary institutions tend to be larger and better able to afford the investment required to create effective online courses.

The answer for secondary education is to form cooperatives of schools to share online courses. If each of 200 schools teaches a section of an online course, then all of their students have access to a pool of 200 course sections. Rather than competing for students in a zero-sum game, everyone gains from this form of sharing. The costs are low, too, because schools in a cooperative don't have to pay tuition. If they balance out the number of seats they create through offering courses with the number of seats their students need, there are no new instructional costs. Of course, there are administrative costs in running the cooperative and training the participating staff, but these are less than tuition.

Much to my delight, a proposal based on this radical idea was funded by the Department of Education's Technology Innovation Challenge program and resulted in the Virtual High School (see http://vhs.concord.org). Through four years of operation, we have demonstrated how such a cooperative can work. We have learned how to prepare teachers to offer online courses, how to keep standards high, and how to handle all the problems of scheduling, registration, orientation, and accreditation.

The conclusion by independent evaluators from SRI International is that students, teachers, unions, and administrators love the VHS online courses. They are personal, challenging, and interesting. The courses offer quality, flexibility, and scope that is invaluable. Their range of topics is a godsend to students with specialized interests. Tiny schools can offer a range of courses that is the envy of larger schools not in the program. At least two smaller schools were saved from oblivion because of this.

The cooperative nature of the VHS is a key innovation that will prove essential in the long run. Some states, such as Florida and Kentucky, are beginning to offer online courses funded at the state level. These are doomed because they represent a major shift of instructional costs and control from the community to the state. In the end, the states cannot afford this shift and communities and unions will not permit it. Similarly, for-profits or entrepreneurial colleges cannot expect to earn more than a tiny fraction of secondary school instructional costs because schools will want to keep those funds in the community. A larger district, however, should be able to sustain effective online courses in its high schools because it can act like a cooperative, sharing among schools instructional resources in the form of online courses.

Once the idea of online courses takes off, it could force some much-needed change. Advocates of vouchers and charter schools hope that the competition that their innovations introduce into education will provide incentives for all schools to improve. Cooperative online courses actually create a far more intense pressure to change, but without the competition. Once schools can offer hundreds of high quality online courses, parents and students will have little tolerance for sub-standard face-to-face courses. There will no excuse for courses that do not use technology well, that are not carefully designed, or are out-of-date. Students will protest with their feet and parents will demand access to the better online courses.

Online courses could be the quickest way to disseminate new instructional approaches that make full use of modeling and data tools. At first, these new approaches will attract only a few students. The strength of online courses, however, is that they can reach thin audiences—those adventurous students willing to try a new approach. As data accumulates about the power of these alternatives, there will be demand for additional sections. As the next section describes, we can train these teachers online and disseminate the approach widely.

The creation of educational cooperatives is an example the kind of structural shifts that are needed to exploit the information technologies. To exploit the power of online course, it is not sufficient simply to offer some courses. A set of economic, political, and practical problems must be solved which seem to demand cooperative sharing of courses.

Online Courses for Teachers

Effective online courses can revolutionize teacher professional development (TPD). They are able to deliver focused and timely assistance to teachers whenever they need it. Online teacher

professional development during the academic year allows teachers to experiment with the new materials and approaches advocated in a course and then discuss the results with their colleagues. Inherently, the costs for effective online TPD are lower than face-to-face courses and workshops because they avoid transportation, food, and meeting expenses.

One of the most exciting current developments in TPD is the use of online interactive video case studies in online courses. The technology is nearing the capacity to handle video on demand, at least in short segments. This allows us to imagine that large numbers of videos of exemplary teaching could be made widely available. It is well known that video case studies, properly supported, are far more effective for teacher than hours of abstract discussions or readings of how to teach. A video shows an entire environment, illustrates how to organize classroom space and time, and how respond to students' typical issues.

Online video case studies could be made highly interactive by linking them to lesson plans, typical student work, relevant standards and assessments, background content, expert commentary, teacher reflection, and moderated online discussion groups. As appropriate to the topics, there will be links to relevant tools, simulations, and implementation guidance. At any point, the user could stop, replay, jump ahead, or dive into the rich surrounding content.

Using interactive case studies in online course will be much richer than typical workshops that use case studies. The online teacher will be in charge, able to control the pace and depth of the experience. The privacy of the experience will permit teachers to acknowledge their content weaknesses and brush up on their understanding of content and technology. On the other hand, the online discussion areas will encourage collegiality and reflective sharing around focused, relevant issues.

The rapid changes in standards, assessment, content, curricula, and educational technologies create a massive need for ongoing teacher professional development. Technology itself puts new burdens on teachers. It is increasingly clear that every school will have a unique and rapidly changing combination of computers, networking, and software. Teachers cannot rely on textbooks to provide software and network resources coordinated with the text because they cannot be sure what technology will be available. Consequently, the task of integrating technology is left to teachers.

Teachers need detailed and specific help in adapting to these changes and new responsibilities. One teacher might want ideas for modeling software to use in eighth grade mathematics, while another might be looking for curricula that integrate conflict resolution into fifth grade. A high school biology teacher might be looking for some background in chemical bonding that is now in the standards. It is very difficult for schools to provide high-quality professional development opportunities for their teachers that are so specific.

Online courses, on the other hand, can reach thin markets with excellent courses designed by the best people in the field. While enough teachers to make up a workshop from one school are unlikely to need the same highly focused course, it is likely that a critical number can be found across the country on almost any conceivable topic. To make this point, the University of Montana's NTEN project started with a course on teaching general relativity in high school offered by experts in the field. The regularly filled the course with 25 teacher participants.

Dropouts have been a persistent problem in online courses. Many teachers who are enthusiastic about online courses and praise them for what they have learned, fail to complete their courses. One exception has been the courses we offer in the VHS that are a prerequisite to teaching in the VHS. Here, unlike many TPD situations, successful completion is an absolute requirement for continuing in the project. The problem is that teachers are incredibly busy and are seldom given released time for online TPD. In addition, there are seldom strong incentives for completion. The upshot is that even conscientious teachers tend to stay enrolled just long enough to get the materials and main ideas and then leave. This means that online courses should be

short and highly focused and that successful completion should well rewarded. Teachers should be able to select exactly the content they need and be able to absorb it in minimal time.

What is needed, then, is the development of very large numbers of targeted online short courses for teachers that make liberal use of video case studies. These should be a half-semester long and accredited by a rigorous, external body. Schools need to expect their teachers continually to complete short courses that fit into the school's master plan for TPD, provide released time for the courses, and link advancement to successful completion.

We have begun to explore these ideas in a one-year pilot program just funded by the Department of Education called Seeing Math. With our partners COMAP[4] and TeachScape[5], we will produce online case studies and short courses for teachers focused on grade 4-5 mathematics. We are hopeful that this project will demonstrate the power of interactive video case studies and short courses that use them.

A much larger effort is needed, however. Hundreds of case studies and short courses are needed to meet the diverse needs of teachers. This suggests cooperatives, designed along the lines of the VHS. If every district in a 200 school cooperative contributed a short course on a topic for which they had expertise, then teachers in all the participating schools would have 200 short courses to choose from. This would result in better use of existing PDF funds; the only new cost would be for the short course development and the administration of the cooperative.

Again, we see structural changes are needed to exploit the technology. In addition to the high bandwidth and modern computers needed for video-on-demand, full exploitation of the technology for TPD demands new cooperatives and accreditation functions, local support for online learning, and increased reliance on ongoing TPD.

Metacourses

Designing and offering courses online requires skill, knowledge, and discipline. The reason there are so many poor online courses is that teachers and entrepreneurs assume that this is an easy task for any teacher. To fill the need for disseminating the knowledge we have gained, we created "metacourses", online courses about online courses. For instance, in the VHS course we have developed two that are central to the success of the project. The first is a yearlong 125 hour course about designing, creating, and offering a VHS course. The second is a one-semester course on how to offer an online course. As part of a different project, we have developed "Moving Out of the Middle", a popular course on facilitating online courses..(For more about these metacourses, see our commercial partner On Line Learning International at http://metacourse.com)

The nation needs many more secondary teachers trained in online courses. If we can get to college students who are making career choices, the opportunity to teach online might help attract more well qualified students into teaching. Being able to teach online can solve the problems of two jobs for married students. The ability of one spouse to teach online vastly simplifies the choice of location and opens more options for the other spouse. In addition, online teaching is likely to be well paying because the online teacher can accept the best job anywhere. The opportunity to earn more and telecommute anywhere might be deciding factors for attracting outstanding students interested in teaching but discouraged by pay and working conditions.

As a start in this direction, we have offered the one-semester VHS metacourse to preservice students. We have long dreamed of offering virtual internships in the VHS for preservice teachers, but have yet to find funders that idea. Again, a much larger metacourse effort is

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[4] See http://www.comap.com

[5] TeachScape will market the fully interactive version. See http://teachscape.com

needed. Schools of education and licensing agencies will have to agree that online teaching is realistic option for students and that there are important things to learn about online teaching. This is likely to take decades without a concerted research and development effort.

Conclusions

Schools need to undertake major changes to fully exploit technology. Students will need increased access to technology. This will make it feasible to rely more on tool-type applications. Realizing the potential gains in learning will greatly strain schools. Teachers will need increased professional development in both content and the use of technology. Online courses will provide models for how to do this along with new opportunities for professional development. Online courses will also provide the spur of competition. Students and parents will demand face-to-face courses of the same quality available online. If schools cannot meet that demand, they will loose students to home schooling or alternative schools better able to exploit the technology.

Funding agencies could greatly accelerate the changes needed to realize these dreams. Small studies are needed to find out what technology-enhanced learning is possible under ideal conditions. Large-scale, longitudinal experiments are need to work out the bugs and document the gains in student learning that are possible. Funding should be provided to develop and disseminate the needed online professional development and the training of online facilitators through metacourses. Most importantly, concentrated funding is needed to seed an international educational open source effort.

Schools and funders need to realize that fundamental structural changes are needed. While the predictions of this paper are unlikely to be terribly accurate, we can be sure that this revolutionary new technology will force fundamental changes in education. We cannot afford public education to go the way of the sailboat or ice companies. Trying to use technology to solve today's problems is like using steam power to get out of the doldrums or ice machines to make block ice. The technology offers education much more.

Visitor

Campus Life
Academics
Main Office

What is VHS?

Where is VHS?

Statistics

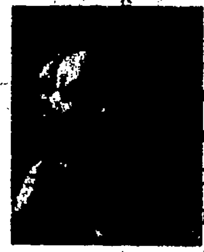
What's the Buzz?

Media Coverage

Project Evaluation

Sponsors

Feedback



Robert Tinker has, for a quarter-century, pioneered constructivist approaches to education, particularly novel uses of educational technology in science. In the '80's, he developed the idea of equipping computers with probes for real-time measurements and of using the network for collaborative student data sharing and investigations. Four years ago he started the Concord Consortium so he could concentrate on applications of technology in education. He now directs several major research and development projects and a staff of 35. Current research includes work on educational applications of portable computers, large-scale tests of online courses for teachers and secondary students, sophisticated simulations, the development of technology-rich materials for sustainable development education, and a scientific study of haze that involves students. Bob is also co-PI for the Center for Innovative Learning Technologies co-located at Concord, Berkeley, Vanderbilt and SRI International, an international center designed to stimulate collaborative, cross-sector research and development on educational technology. Bob earned his PhD in experimental low temperature physics from MIT and has taught college physics for ten years.

The Virtual High School